16149

DEVELOPMENT OF A PRACTICAL HOLISTIC VEHICLE THERMAL MODEL (U)

J. Perez
J. Jones
P. Rogers
AMSTA-TR-R, MS263
TACOM, Warren, MI 48397-5000

ABSTRACT (U)

(U) Thermal modeling for military applications has historically focused on vehicle thermal signature or component engineering evaluation. The modeling tools vary drastically depending on the intended purpose. This paper identifies a modeling approach that produces a holistic vehicle thermal model applicable to signature evaluation, HVAC heat load assessment, and component thermal load evaluation.

(U) BRL-Prevu, Eclectic, and MuSES greatly simplify the modeling process and make it possible to model the complete vehicle system. BRL Prevu enables component selection and geometry manipulation. Eclectic uses a surface sampling process against existing CAD geometry to produce a well-conditioned mesh. MuSES obtains the model's thermal solution using a finite difference approach. Models can now incorporate electronics and crew thermal footprints in conjunction with power train and environmental sources. This makes a total energy balance analysis possible. Conversion of chemical to mechanical/electrical to thermal energy is predictable and traceable throughout the system.

(U) This paper discusses the model building process for a holistic vehicle thermal model applicable for signature and engineering analysis. Key issues such as model fidelity, mesh construction, and vehicle component omission are investigated. Integration of BRL-Prevu and Eclectic is demonstrated. The Bradley is used to illustrate the model building capability of this suite of computer codes.

(U) Introduction

(U) Model building requires an optimal continuity between geometry construction, mesh resolution, and thermal solver requirements. Each stage of the process has a direct link to the next. Failing to plan the model development with this in mind may lead to a poorly constructed final product.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **04 APR 2002**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Development of a Practical Holistic Vehichle Thermal Model**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **J. Perez J. Jones P. Rogers**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **USA TACOM 6501 E 11 Mile Road Warren, MI 48397-5000**	8. PERFORMING ORGANIZATION REPORT NUMBER **16149**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

(U) Success in model building is dependent on the modelers' knowledge of the available tools. Having a working knowledge of thermal solver requirements is very important. The model must have a structure compatible with the thermal solver or inaccuracies or poor convergence results. Understanding the types of mesh that work well with the thermal solver will help avoid poorly constructed meshes. Learning the basic functioning of the programs and how they interact will minimize unnecessary frustration during the model building process.

(U) Modelers strive to make each model precise. In many cases a highly detailed and perfect model may not be necessary for the study objective. Identifying desired goals and available options might prevent wasted effort. In some cases, a simple model can produce results just as effectively as one that is extremely detailed. Experience is the best teacher when it comes to choosing the resolution of a model, but other factors also play a part. Computing capability and file size restrictions within the solver code are potential restrictions on the resolution of the model. It is important to be aware of the limitations of the tools.

(U) Choosing which components of the geometry are important is another challenge. Larger more detailed geometry makes the selection process more crucial. When modeling a full vehicle, smaller items become trivial in terms of contribution to the overall model accuracy. Identifying components for exclusion is an important step. Omitting the wrong components may invalidate your final results. On the other hand, removing trivial components reduces the size of the model and allows for the placement of higher resolution mesh in areas of interest.

(U) Determining the best route to take for the given situation is an iterative process. Complete understanding of the model criteria and the tools available can help reduce the number of iterations required. Realizing the needs of the thermal solver positively impacts early decisions and helps streamline the model building process.

(U) <u>Programs</u>

(U) Successful modeling results rely on quality geometry and surface mesh. An accurate geometry is the foundation of any model. The ability to edit and manipulate the geometry into the form most compatible with your meshing program simplifies the process. However, model quality ultimately depends on the quality of the mesh. Having a program that is easy to use can significantly reduce the workload associated with meshing large geometry assemblies. The following paragraphs describe tools available to build a mesh and perform geometry editing.

(U) <u>BRLPrevu</u>

(U) An auxiliary program, BRLPrevu, extends control over the incoming geometry. The BRL tree structure is displayed in a "List View" format as shown in Figure 1. The user has the ability to preview the model and select which parts to import and to control how

the parts are faceted. They may choose to omit insignificant cuts, such as boltholes. In the case of nested cylinders, such as a road wheel, the user can change the default number of sides on each cylinder to ensure they correspond. In a case where the modeler would want a single cylinder to represent a more complex road wheel, the program displays the original volume of the part ("as modeled") and the new volume ("as imported"), which would be considerably greater. The user could then specify the "As Modeled" volume, which would override the value that Eclectic would otherwise calculate at import.

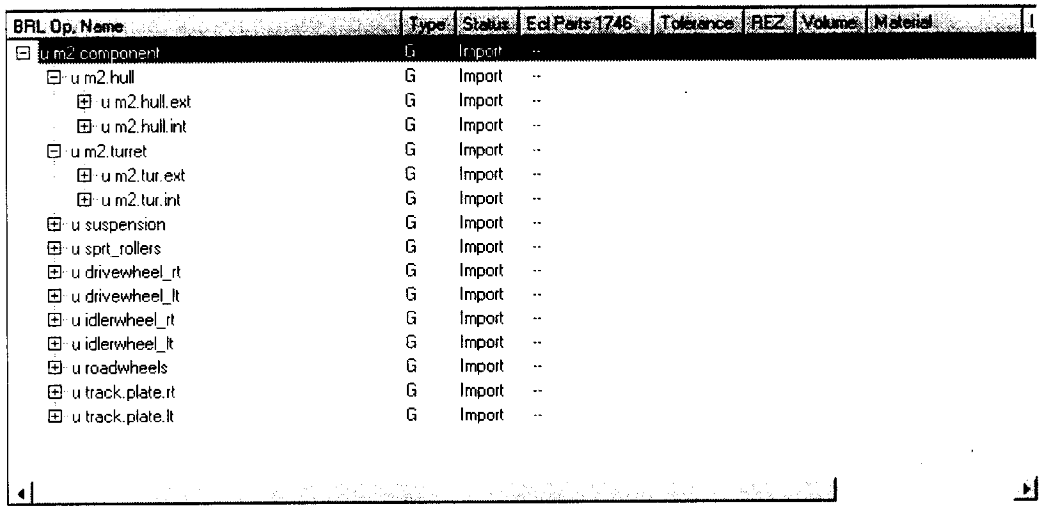

Figure 1. (U) BRL Tree Structure.

(U) BRL CAD uses Boolean algebraic operations to build geometry. It builds solids with geometric primitives. Combining the primitive shapes or cutting away primitive shapes from each other allows the development of complex geometry. Thermal modeling calculates the energy exchange via component interfaces. The accuracy of the energy calculation is a function of the interface quality. When the solids join to make a shape, they do not always join in a way conducive for thermal modeling. Most times gaps occur [1]. BRLPrevu allows tolerance adjustment to decrease gap occurrence. A "correct" tolerance for every part (region) in a model does not seem to exist. The volume of each region is tested to see that it's exactly enclosed by triangles. A confidence number for each is displayed, with one hundred (100) meaning the region is good. The user may tweak the tolerance, iteratively, for each region in hopes of obtaining a better result.

(U) BRLPrevu writes a companion file "name.ascmap" to the BRL-CAD file "name.asc". The file contains all the user preferences (i.e. changes made to geometry such as tolerance changes, parts marked for omission, etc.) in order that Eclectic "gets it right" the first time. The process is an excellent way of tackling a very large BRL model such as the Bradley. Each sub-system of the model goes through the process independently.

(U) The ability to alter geometry before importation into the mesher is a significant time saver. BRLPrevu lets the modeler manipulate the geometry into a form that is much more compatible to the mesher.

(U) <u>Eclectic</u>

(U) Eclectic is an alternative to starting from scratch when constructing a model to meet the MuSES requirement for a well-conditioned surface mesh. It converts constructive Solid Geometry, such as BRL-CAD, into a shell of polygons that enclose the volume of the solids. A grid box, based on a given mesh size, is created to completely enclose the model. (fig.2) The program fires a vector at the model from each knot on the grid. The coordinates where the vectors strike the model form the corners of the individual mesh elements.

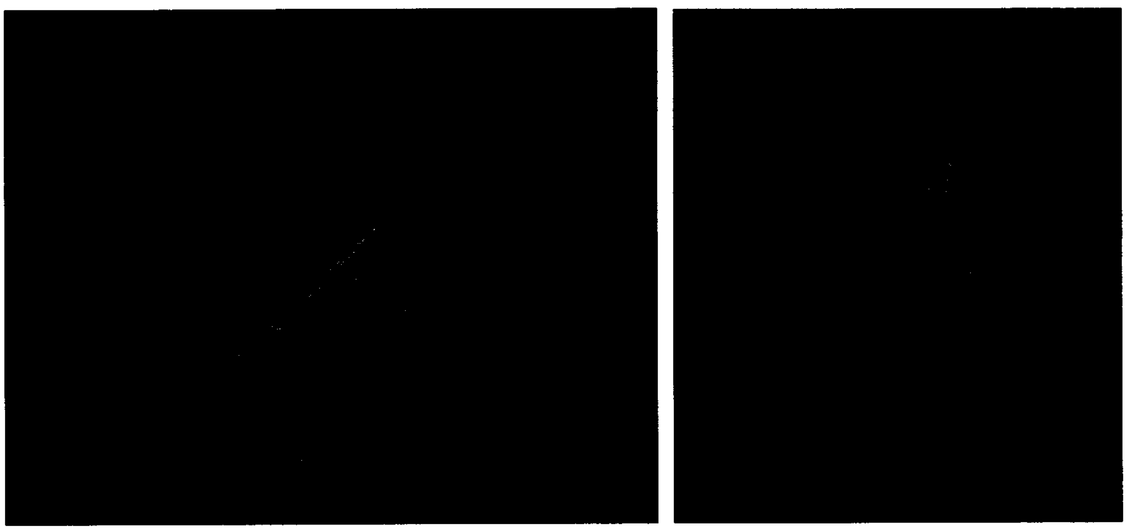

Figure 2. (U) Mesh Building in Eclectic. Left: Eclectic Grid Box. Right: Completed mesh.

(U) The user determines the surface to mesh and controls whether the surfaces will be connected to each other along their edges. In the case of a hatch, the user could alter the mesh parameters in such a way as to disconnect it from the rest of the body. Close inspection of figure 3 shows discontinuity between hatch nodes and hull nodes. The discontinuity prevents thermal conduction calculations at the intersection of the hatch and hull. Eclectic samples each surface to produce the polygonal mesh consisting of mostly quadrilaterals and some triangles to conform to the hatch outline. In the end, Eclectic would assign a thickness to each surface so that they would accurately represent the volume of the original part. The mesh, thickness, and material properties contained by the model are now ready for import by MuSES.

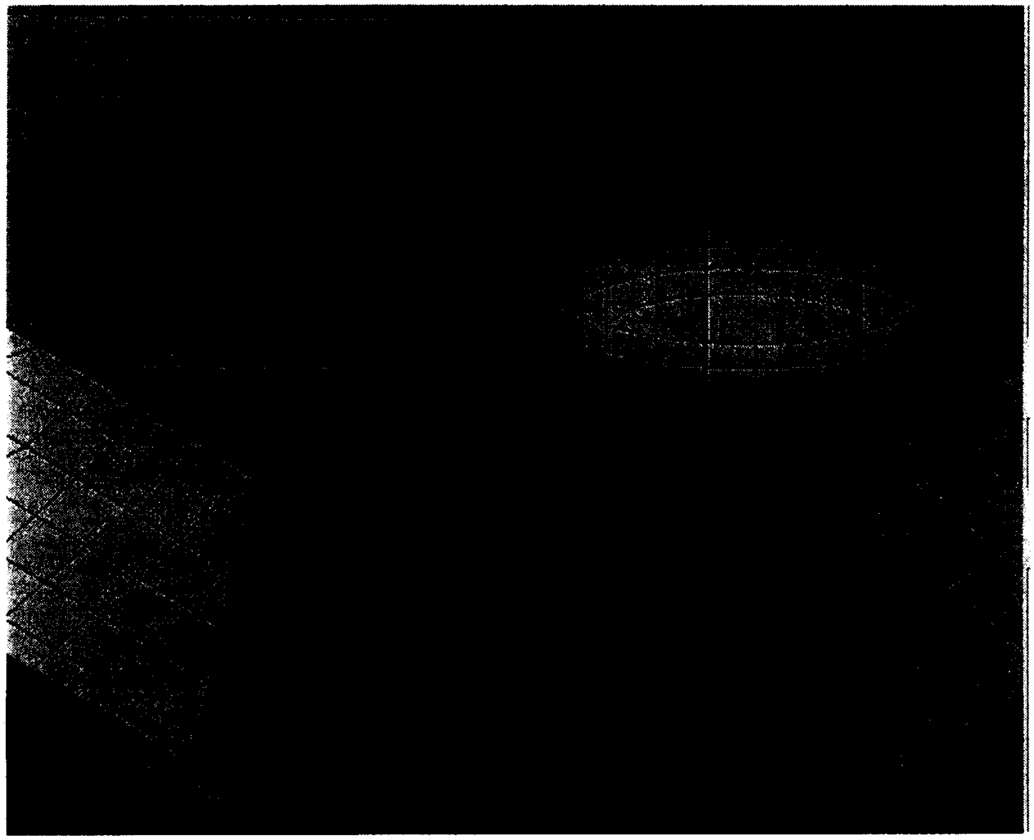

Figure 3. (U) Using Mesh Parameters to Disconnect Geometry. By using different resolution mesh on components, the user effectively disconnects the geometry. If the mesh nodes do not connect, the thermal solver will not calculate conduction between the components.

(U) Model Development

(U) To successfully build a model, several essential components must be available. The first component needed is an accurate and editable geometry of the vehicle. The geometry has to undergo manipulation from its raw state into a form that possesses the highest level of compatibility with the meshing program and thermal solver. The challenge lies in reaching the desired compatibility level without compromising the integrity of the original geometry.

(U) The M3 Bradley Fighting Vehicle is the subject of this study. The base geometry is available from a BRL CAD file. The file contains over 7500 solids, which translates into nearly 1800 parts. Nearly all of the parts had geometry unnecessary for a thermal model. The user trims the model down in size using BRLPrevu. This is a time consuming task. Dividing the geometry into subsystems simplifies the process. Insignificant items, such as wires and ammunition, are omitted and significant thermal contributors are retained. Some examples

are the engine, drive train, and electronics boxes. The exported Bradley file contained 900 parts after reduction.

(U) The second component needed is a good meshing program. Creating a mesh for any given geometry is one of, if not the most difficult, steps of the modeling process. Meshing is time consuming and very tricky for non-standard shapes. To add to the level of difficulty, the mesh will determine if the model will succeed or fail in the thermal analysis stage. Failure would consist of the model not converging on a solution. Lesser forms of failure are converging slowly and converging inaccurately. With a failure at any level, the model has to be refined. The accuracy and convergence of the model depend primarily on the quality of the mesh.

(U) Generally the most accurate mesh style for a thermal model is one consisting of near unity polygons. This can create a stiff challenge for the modeler, especially if the geometry has numerous cylinders or spherical shapes. Some mesh styles are detrimental to thermal modeling and the user should avoid them if possible. Two such examples are elements with high aspect ratios and instances of numerous elements converging on one point (i.e. pie slices). Figure 4, shows an example of these poor mesh elements and an alternate solution [3].

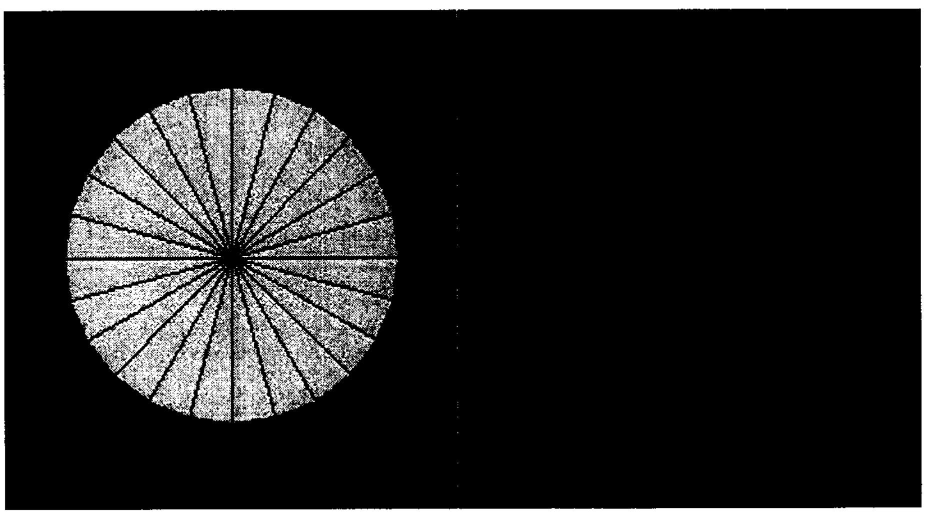

Figure 4. (U) Mesh Element Examples. Left: Drive wheel mesh displaying high aspect ratio triangles and "radiating" elements. Right: Drive wheel mesh displaying near unity aspect polygons as an alternate solution [3].

(U) Meshing follows after the geometry is clean and ready to export. The easiest approach is to break the geometry into major components and mesh each one, then append them and stitch the mesh together at the points of contact where conduction occurs. Inevitably geometry won't export cleanly and newly added polygons confuse the mesher. Fortunately, it is

easy to spot when this happens as shown in figure 5. The rogue polygons must be found and removed prior to creating the mesh.

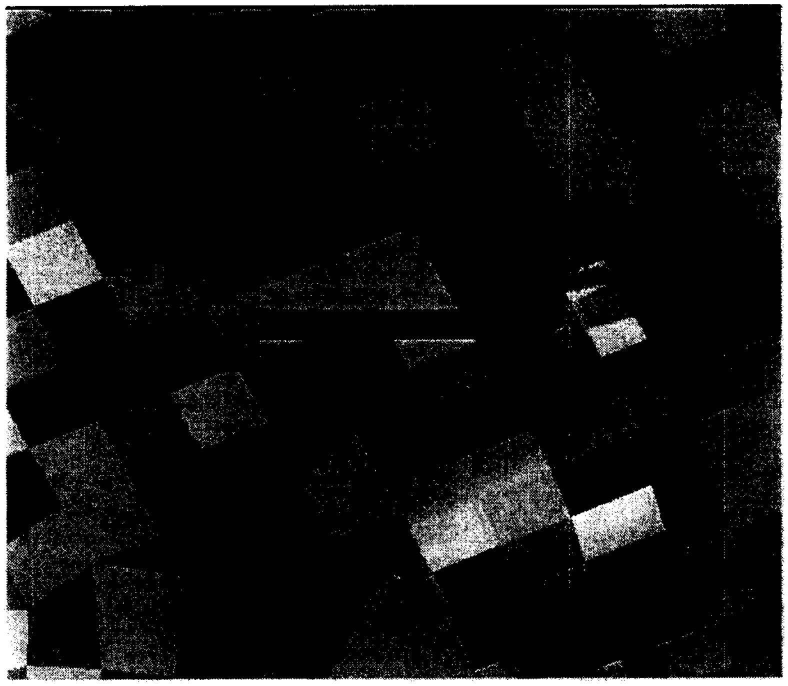

Figure 5. (U) Extra Polygon Created During Importation. The Eclectic screen shot shows an extra polygon created during the BRL CAD file import. The polygon is highlighted in yellow.

(U) A thermal model is more accurate if the mesh consists of polygons with an aspect ratio near unity [3]. Achieving near unity polygons is a challenge for spherical and cylindrical geometry. Eclectic allows the user to build a grid box for an individual surface. This is very handy for meshing the faces of cylinders. The mesh starts as a single square in the center of the surface and builds outward. When the surface is circular, like a cylinder, the mesher will use some triangles to complete the face. Depending on the desired mesh size, the mesher may have difficulty fitting polygons with an aspect ratio near unity. After several iterations the user may determine that the geometry is in need of refinement. Increasing or decreasing the cylinder resolution, or number of sides, may improve the meshing results. Figure 6a and 6b shows an example of cylinder resolution changes.

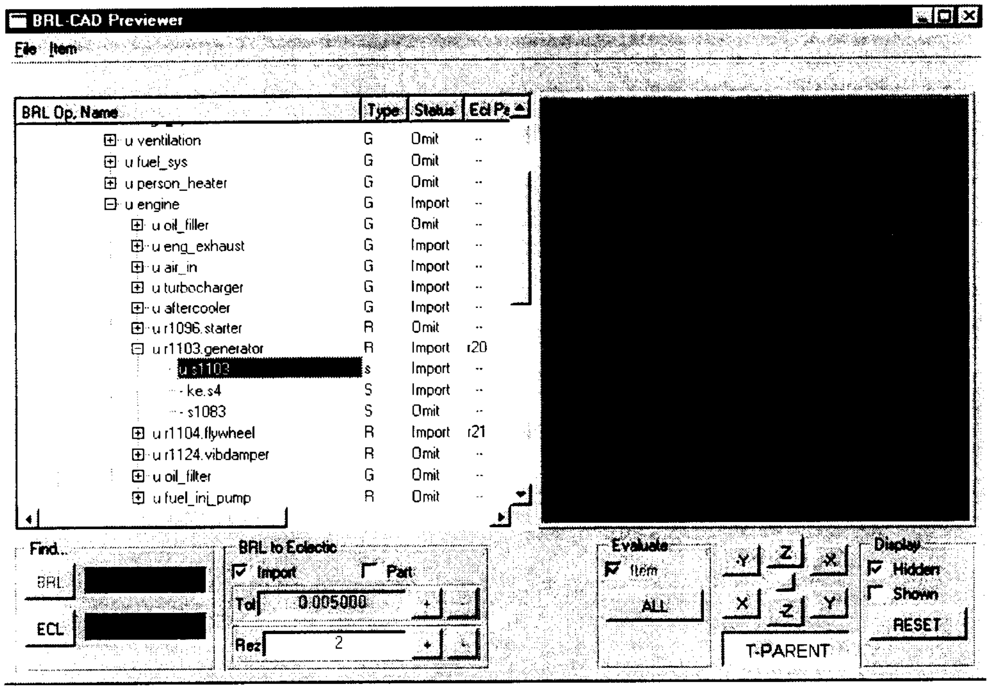

Figure 6a. (U) Original Cylinder Resolution. This screen shot from the BRL CAD previewer shows the generator, a cylindrical shape, before adjustment. Note the resolution (Rez) setting of 2.

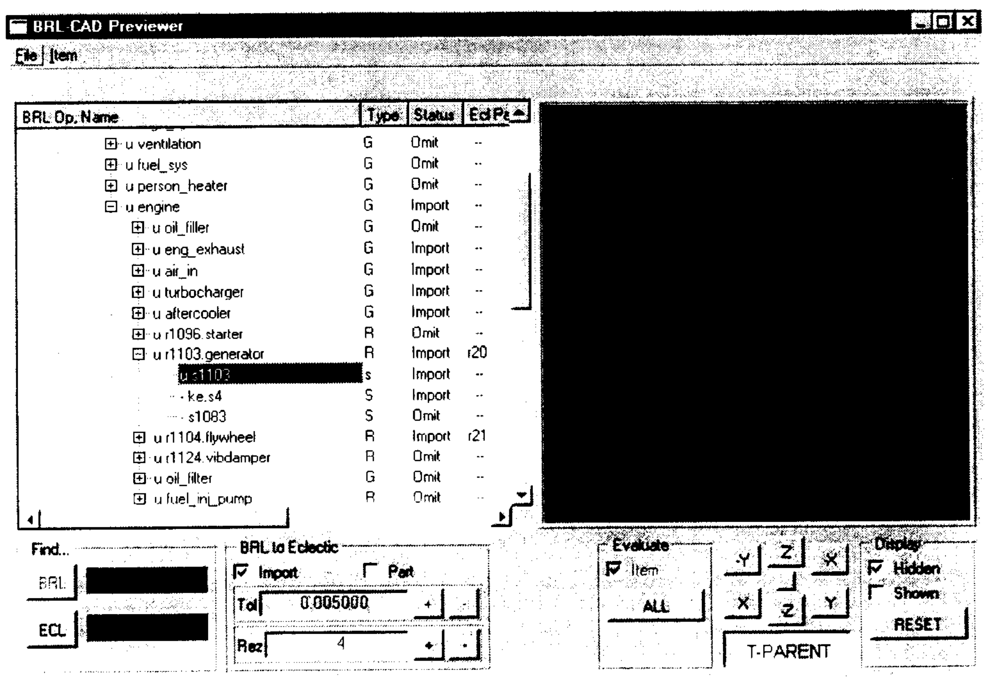

Figure 6b. Adjusted Cylinder Resolution. This screen shot from the BRL CAD previewer shows the generator, a cylindrical shape, after adjustment. Note the resolution (Rez) setting of 4.

(U) A possible problem when importing BRL CAD geometry is the alignment of mated components. A clean interface is important if the two misaligned parts experience conduction between one another. An example is the Bradley personnel heater and ductwork illustrated in Figure 7. Individual exhaust pipes do not align properly. If left uncorrected, inaccurate thermal conduction calculations result. This situation also makes it difficult to produce a clean mesh. An Eclectic editing feature allows the user to create fillets at the junctions where the pipes are misaligned. This allows the thermal solver to make the correct conduction calculations, restoring accuracy to the model.

(U) It is necessary to identify points of contact between parts following assembly. If two parts experience conduction the mesh is stitched together at each node. The geometry is now ready for export to MuSES.

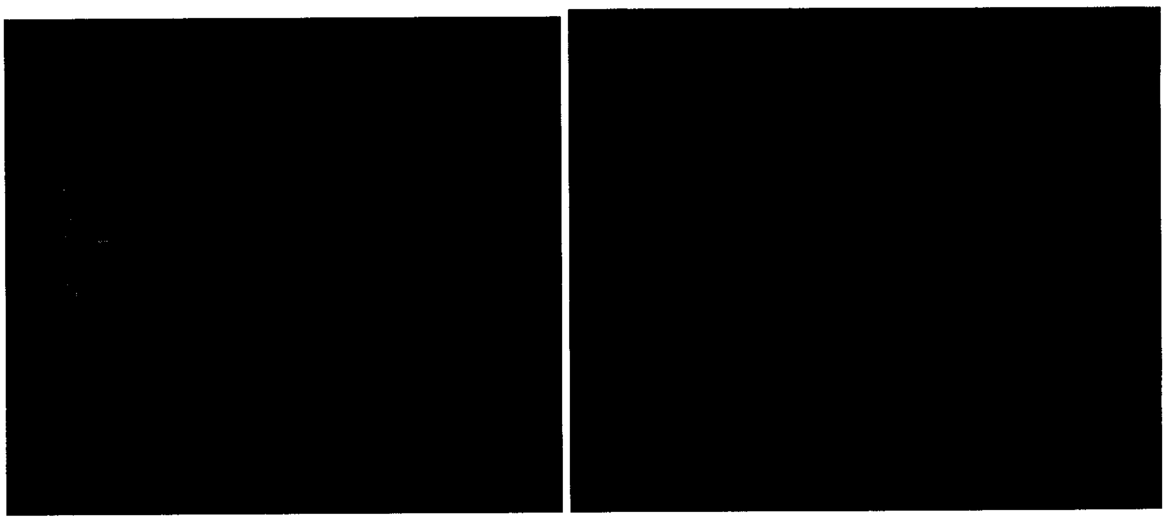

Figure 7. (U) Misaligned Geometry. Left: Raw import. Right: After fillets were created.

(U) Model resolution and computing power are often at odds. Mesh resolution determines the overall resolution of the model. The modeler must use discretion, founded in experience, to determine where high-resolution mesh is required. Some component thermal characteristics support a minimal resolution mesh without affecting the model accuracy. To accurately capture a temperature gradient the modeler must build a high definition mesh on the component in question. If a low-resolution mesh is used, the solver will only calculate an average uniform temperature and not depict the presence of the gradient. If a component has a uniform temperature, a high definition mesh wastes computing power since a few data points establish the uniform temperature.

(U) The modeler must understand how the thermal solver interprets geometry and creates parts. For example, MuSES interprets geometry as a surface mesh. The user then inputs

the thickness of the part to create the volume. This is an issue when dealing with parts such as boxes. The modeler must determine the best way to model the box. Does the desired result require a box with six separate plates or is the same result achieved with a single 'equivalent volume' plate? Understanding how the various components interact in the thermal solver allows the modeler to accurately define parts in a manner that will achieve accurate solutions.

(U) Conclusion

(U) Even with easy to use computer programs, building a model remains a challenging task. Clearly defining the requirements of the model is the key to achieving the desired goal. With defined objectives, the modeler can manipulate the geometry into the best form to produce a valid solution.

(U) Model building requires an optimal continuity between geometry construction, mesh resolution, and thermal solver requirements. Each stage of the process has a direct link to the next. Failing to plan the model development with this in mind may lead to a poorly constructed final product. Several tools for thermal model development were discussed in this paper. BRLPrevu enables component selection and geometry manipulation while Eclectic provides a means to creating a thermal mesh.

(U) References

[1] G. Bobo, T. Gonda and J. Jones. HMMWV Thermal Signature Model. In Proceedings, 6th Annual Ground Target Modeling and Validation Conference, pages 529-538, 1995.

[2] R.Haase, D. Strang, W. Reynolds, and B. Conway. Modeling of Internal Thermal Sources in the M1025A2 HMMWV. In Proceedings, 8th Annual Ground Target Modeling and Validation Conference, pages 227-233, 1997.

[3] MuSES 6.0 Training Manual, ThermoAnalytics, Inc., Calumet, MI, 2000.